

The Gender Factor Performing Visualization Tasks on Computer Media

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Abstract

There has been a recent trend to develop new, complex, and often predominantly visual, user interfaces as media ‘front ends’ to computer applications. This trend assumes that varied user groups have equivalent propensities to perceive, interpret, and understand the multi-dimensional spatial properties and relationships of objects visually presented through the on-screen medium. However, it is well known that there exist gender differences in certain spatial abilities, suggesting that there may be gender biases to effectively utilize certain visual cues presented through computer-mediated interfaces. We test this notion with three experiments (object matching, positioning, and resizing) using 2D and 3D computer screen media. Whereas female subjects under-perform male subjects in the object matching and positioning tasks, they outperform male subjects in the resizing task. Implications for the design of gender-effective user interface media are discussed.

1. Introduction

A clear trend in the historical evolution of computer technology relates to the ever-increasing power and complexity of hardware and software. This trend has enabled burgeoning opportunities to develop numerous computer applications to support users in a myriad of personal, professional, commercial, and societal roles and tasks. Also associated with this trend is the challenge to make the presentation of data ever more concise, condensing and conveying large amounts of useful information into smaller and smaller spaces. New approaches in the design of visual user interface media have appeared, many that present complex, and often multi-dimensional, data sets into condensed visual forms and spaces.

However, an implicit assumption in the design of novel, visual user interface media, is that large segments of the using population possess equivalent propensities

to perceive, interpret, manipulate, and understand the visual and spatial properties of the objects presented through the media. Clearly, this assumption runs the risk of impairing the usability of visual interface media that fail to account for broad, existing population anomalies. For example, experienced web designers are aware that large segments of internet users, perhaps as many as 10% of all males and 0.5% of all females, are characterized by patterns of color blindness that impact their ability to correctly perceive certain shades of color-encoded information. As a result, developers of well designed, high traffic, usable web sites anticipate and avoid these ‘color blindness traps.’ However, although acknowledged by behavioral research communities, it is less well known in the user interface design community that there are gender differences in innate cognitive spatial abilities. These gender differences may relate directly to the perception, interpretation, and cognitive processing of spatial properties, and spatial relationships, of visual objects presented through computer media.

However, although there are gender differences performing spatial tasks in the ‘real world,’ it is not a foregone conclusion that these gender performances differences automatically carry over into computer-based media. It has been documented that large segments of the population understand information presented on computer media very differently from when this same information is presented through print media. For example, it is well known that the same textual information presented through printed media is perceived and interpreted differently through computer media. Nielsen [33] notes that people read approximately 25% slower on computer screens as compared to traditional print media, and that they understand and can find information presented on computer media more readily when this textual content is presented in a short, concise, scannable, and ‘chunked’ format, using bullets to summarize content, and emphasizing an ‘inverted pyramid’ style of paragraph writing.

In this study, we review theoretical and empirical literature relating to: (1) gender and human computer interaction; and (2) gender differences in spatial abilities.

We then relate and extend these threads of research with three experiments that examine gender-based differences performing visualization tasks presented through 2D and 3D computer media. Findings are discussed with respect to relevant theory and with respect to the design of ‘gender-neutral’ computer-based user interface media.

2. Theory and background

2.1. Gender and human computer interaction

Researchers have long recognized the relevance of gender as impacting human computer interaction. Gender has been recognized as a broad issue affecting computer skills and computer design issues [2]. Gender has been singled out as an important variable in the design of user interfaces [22] and display techniques [39] and as an important user diversity issue for achieving ‘universal usability’ of web-based and other computer services [40]. Gender has been related to the process of decision-making, and to preference of investment models, and, consequently, as an important variable in the design of financial [34] and organizational decision support systems [35] for men and women. Men and women have been shown to have different perceptions and preferences with respect to the use and satisfaction with different features of electronic commerce web sites [44].

Numerous researchers have noted gender differences interacting with computers. For example, it has been demonstrated that boys and girls think about computers differently [12] [52], have different motivations for using computers [18] [46], and exhibit different preferences and usage styles [18] [24]. However, Inkpen [17] did not find a main gender effect on point-and-click versus drag-and-drop interaction styles with children. Moreover, Rieman [38] found that gender did not have a significant impact on the number of reported exploratory learning discoveries using new systems. Hinckley, Pausch, Proffitt and Kassell [15] reported that females performed a two-handed, three-dimensional neurosurgical visualization (manipulation) task faster than did male subjects, and suggested that females may outperform males at some dexterity tasks [13] [14].

2.2. Gender differences in cognitive abilities

The investigation of male-female differences in cognitive abilities has been an active area of research for decades. Although cognitive performances of both genders have been shown to overlap to a large degree [31], numerous studies have reported that men tend to outperform women in particular (but not all) spatial tasks [13] [16] [28] [48] [50]. Other studies report that women

outperform men in many aspects of verbal ability [29] [13].

Male-female cognitive differences have been attributed to gender-specific hemispheric specializations of the brain [36]. Gender differences in visuo-spatial cognitive processing in particular has been attributed to genetic factors [8] [26], sex hormones [3], as well as to environmental and socio-cultural mechanisms [1] [37]. Vecchi and Girelli [47] demonstrated that gender differences in visuo-spatial abilities are limited to active processing tasks, such as mentally following pathways, but do not apply to passive tasks, such as the recall of previously memorized positions.

One theory that explains gender differences in spatial abilities is Silverman and Eals’ [43] hunter-gatherer theory of the origin of sex-specific spatial attributes. This view holds that men and women have different cognitive skill predispositions, appropriate to handling differentiated sex role aspects of their prehistoric environments. Prehistoric females (i.e. gatherers) who could forage for food and keep track of relationships, activities, objects, locations, and landmarks near their homes were more successful at acquiring resources for bearing and raising offspring. Males (i.e. hunters) who were better able to travel in unfamiliar territory, estimate distance, and navigate with a ‘bird’s eye view’ orientation were more successful at hunting, competing with other males, finding mates, and having children.

Through the process of evolutionary selection, the ‘hunter-gatherer’ theory suggests that these male-female cognitive predispositions persist to this day. In support of this theory, Dabbs, Chang, Strong and Milun [7] demonstrated that contemporary females outperform men on spatial tasks mimicking foraging-related activities, such as remembering the location of objects (i.e. landmarks) in the environment. Women outperform men at keeping track of objects and finding objects that are lost [9] [43]. McBurney, Gaulin, Devineni and Adams [27] reported that women can remember the locations of previously viewed items better than men. James and Kimura [19] found that women outperform men in remembering specific objects located at specific places. However, men typically outperform women at spatial tasks that involve manipulating objects in space [5] [11] [20] [21] [23] [25] [26]. Furthermore, studies have shown that men have more keenly-honed ‘mental rotation’ spatial abilities than women [7] [42], purportedly as an evolutionary artifact of the ability to pursue an animal through unfamiliar terrain and then expeditiously find their way home.

The basis for gender differences performing external spatial tasks is generally attributed to corresponding differences in innate mental spatial abilities. Although

meta-analytic studies [23] [49] indicate a male advantage on certain cognitive spatial tests, individual studies are often inconsistent in their reported results, as well as with respect to the test instruments used to measure ‘spatial’ abilities. Linn and Petersen [23] clarified this issue by classifying the various instruments reported in the literature into three distinct categories of cognitive spatial tests: those that separately measure *spatial perception*, *mental rotation*, and *spatial visualization*. They describe *spatial perception* as the ability to determine spatial relations despite distracting information. *Mental rotation* relates to the ability to rotate quickly and accurately two- or three-dimensional figures, in imagination. *Spatial visualization* is the ability to manipulate complex spatial information when several stages are needed to produce the correct solution. Linn and Petersen’s meta-analysis reported that men robustly outperform women on *spatial perception* and *mental rotation* cognitive tests, but that there are no consistent gender performance differences on *spatial visualization* cognitive tests.

3. Method

We report the results of three computer-based media experiments that are each based on different spatial abilities tasks: object matching, object positioning, and object resizing. The object matching experiment is designed to largely tap *mental rotation* abilities. The object positioning and resizing experiments are designed to tap *spatial visualization* abilities. Consistent with the spatial abilities literature, men should outperform women in the object matching experiment, but there should be no gender differences in the object positioning/resizing experiments.

These experiments examine whether documented gender differences performing ‘real world’ spatial tasks are observed in similar, representative tasks presented to men and women through computer-based media. Accordingly, the results can extend the existing body of knowledge to the digital world of computer-based media, enabling recommendations and guidelines for designing and creating effective ‘gender-neutral’ digitally-based media interfaces.

3.1. Object matching experiment

The object matching experiment utilized a variant of the *mental rotation paradigm*, first developed by Shephard and Metzler [41]. Presented with pairs of object images viewed at different angles, the task was to determine whether the two images represented identical, or different, objects. Figure 1 depicts an example of an object matching image pair. As soon as a subject made a

judgment whether the two images represented the same or different objects, s/he clicked “same” or “different” on the interface and the next trial was immediately presented. Equally half of the 208 image pairs presented to each subject were, in fact, the same or different.

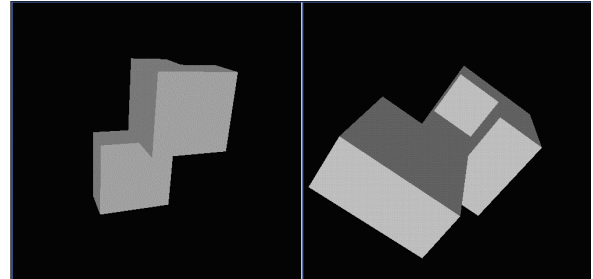


Figure 1. Object matching image pair

In addition to *gender*, the object matching experiment manipulated *viewing mode* (stereo, mono) and type of *motion* (controlled, uncontrolled). The measured dependent (response) variables included *error rate*, the percentage of incorrect responses, and *response time*, measured in milliseconds. One half of all trials were presented in stereo using stereoscopic CrystalEyes™ glasses. The other half of the trials were presented in mono. The left object image in each trial was always stationary while the right image was always in motion. Furthermore, in one half of the trials, subjects could control the motion of the right object image by rotating it around the center point about any direction vector. In the other half of the trials, the right object always rotated automatically in a fixed and random direction and speed about the center point. Subjects volunteered to participate in the object matching experiment, and consisted of 14 female and 14 male professional employees from the Goddard Space Flight Center.

3.2. Object positioning experiment

In the object positioning experiment, subjects viewed computer-generated scenes depicting three identically-sized spherical objects suspended in 3D space (see Figures 2 and 3). The task was to reposition, as quickly and accurately as possible, the *target object* so as to comprise a straight line segment consisting of three spheres located at equal distances from each other. The correct positioning placements were all configured such that the straight line subtended an oblique angle from the viewer’s perspective. Figure 2 displays a typical positioning scene at the start of a trial. One hundred and forty four unique scenes were randomly presented to each subject. Subjects would ‘fly’ the misplaced object

around the scene using a spaceball, a six-degrees-of-freedom input device. When they had positioned the misplaced object, they pushed a button on the spaceball, causing the next scene to appear. Figure 3 displays the correct, completed placement for the initial scene presented as Figure 2. Twenty eight volunteer subjects, 14 female and 14 male, participated. All had professional occupations at the Goddard Space Flight Center.

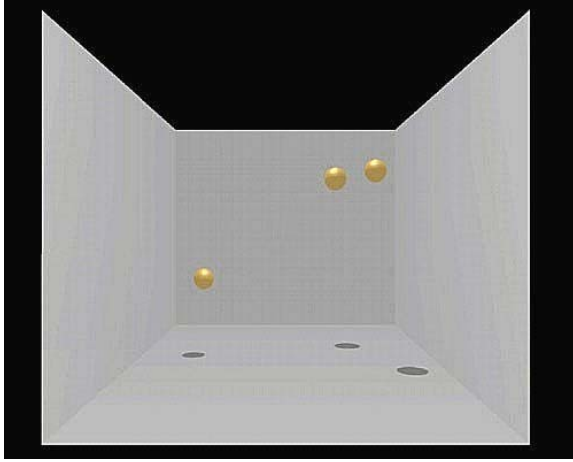


Figure 2. Initial positioning scene trial

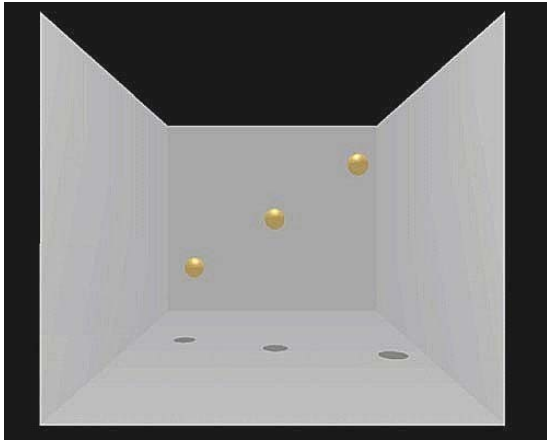


Figure 3. Completed positioning scene trial

In addition to gender, the object positioning experiment manipulated *viewing mode* (stereo, mono); and the presence or absence of cast *shadows*. The measured dependent (response) variables included *distance error magnitude* and *response time*. Distance error magnitude was defined as the Euclidean summation of the three directional errors in the x, y, and z spatial dimensions, or $(e_x^2 + e_y^2 + e_z^2)^{1/2}$. This metric

constitutes the exact absolute distance of the repositioned target object from its correct location in three dimensional space. Response time was again measured in milliseconds.

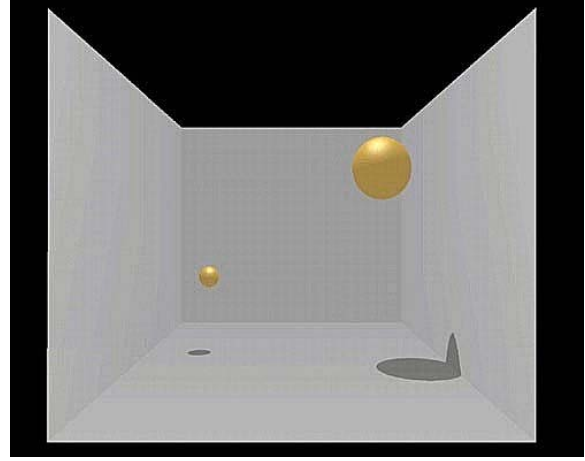


Figure 4. Initial resizing scene trial

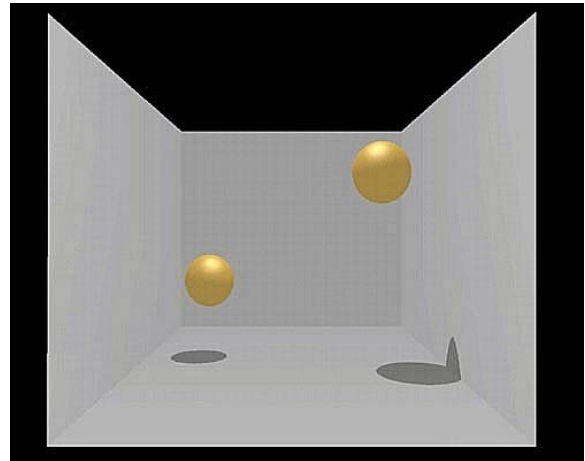


Figure 5. Completed resizing scene trial

3.3. Object resizing experiment

In the object resizing experiment, subjects viewed scenes of two differently-sized spheres suspended, and fixed in position, in 3D space. The task was to adjust the size of the *target object* so as to correspond with the apparent size of the *referent object*. Figures 4 and 5 display a typical set of corresponding initial and correctly completed resizing scenes. One hundred forty four unique scenes were randomly displayed to each subject. The target and referent objects were always displaced at different depths from the viewer. The same twenty eight subjects from the object positioning experiment participated in the object resizing

experiment. Moreover, the object resizing experiment manipulated the same independent variables by gender as the object positioning experiment: stereo versus mono viewing, and the presence or absence of cast shadows. However, the measured dependent (response) variables included *radius error magnitude* as well as *response time*. Unlike distance error magnitude in the object

positioning experiment, radius error magnitude was defined as the absolute value of the difference between the radius length of the resized target sphere compared to the radius length of the correctly-sized referent sphere. Response time was again measured in milliseconds.

Table 1. Means of error rates and response times by gender and depth cue for the object matching experiment

Object Matching	Error Rate (%)		Response Time (seconds)	
	Males	Females	Males	Females
Depth Cues:				
Stereo Viewing	6.75	10.15	11.73	12.85
Mono Viewing	11.95	16.08	13.34	14.23
Controlled Motion	7.04	11.94	12.85	13.95
Uncontrolled Motion	11.66	14.29	12.22	13.13

Table 2. Means of distance error and response time by gender and depth cue for the object positioning experiment

Object Positioning	Error (Euclidean distance)		Response Time (seconds)	
	Males	Females	Males	Females
Depth Cues:				
Stereo Viewing	0.514	0.742	17.74	19.47
Mono Viewing	0.633	0.959	22.52	20.83
Shadow On	0.504	0.756	20.74	20.94
Shadow Off	0.643	0.945	19.52	19.36

Table 3. Means of radius errors and response times by gender and depth cue for the object resizing experiment

Object Resizing	Radius Error (radius length)		Response Time (seconds)	
	Males	Females	Males	Females
Depth Cues:				
Stereo Viewing	0.067	0.061	9.85	10.04
Mono Viewing	0.068	0.064	11.51	11.92
Shadow On	0.068	0.060	10.62	11.63
Shadow Off	0.067	0.065	10.74	10.33

4. Results

4.1. Object matching

The experimental data were fitted to a repeated measures multivariate analysis of variance model (MANOVA). There were significant differences in both error rate ($p = 0.002$) and response time ($p = 0.002$) as a function of gender. The overall mean male error rate was 9.35% whereas the overall mean female error rate was 13.12%. The overall mean male response time was 12.54

seconds whereas the overall mean female response time was 13.54 seconds.

To further investigate the gender-based impact of the depth cues on performance, a MANOVA model tested the effects of viewing mode and type of motion on the object matching error rates and response times by gender. Table 1 presents the mean error rates and response times by gender and depth cue for the object matching experiment.

Both males ($p = 0.003$) and females ($p = 0.003$) made fewer object matching errors viewing stereoscopic image pairs than when viewing monoscopic image pairs.

Moreover, both males ($p = 0.002$) and females ($p = 0.003$) made their matching decisions more quickly when viewing stereo images. Males controlling the motion of the right-hand object image, also called the 'comparison object' (recall that the left image was always stationary) were more accurate ($p = 0.001$) than were males who did not control this motion (recall that in these cases the comparison object rotated at a fixed rate). Furthermore, males controlling the motion *took longer* to make their comparison decisions ($p = 0.013$) than did the males in the fixed motion trials. Unlike the males, females controlling the motion of the right-hand object image were no more nor less accurate ($p = 0.083$) than were females who did not control this motion. However, like the males, females controlling the motion *took longer* to make their comparison decisions ($p = 0.031$) than did the females who did not control this motion.

4.2. Object positioning

In the object positioning task, there were significant differences in distance error magnitude ($p = 0.002$) as a function of gender. The overall mean male distance error was 0.57 units whereas the overall mean female distance error was 0.85 units. The difference in response time as a function of gender was not significant ($p = 0.97$). The overall mean male response time was 20.13 seconds whereas the overall mean female response time was 20.15 seconds.

To further investigate the gender-based impact of the depth cues on performance, a MANOVA model tested the effects of viewing mode and the presence of cast shadows on positioning accuracy and response times by gender. Table 2 presents the mean distance errors and response times by gender and depth cue for the object positioning experiment.

Both males ($p = 0.002$) and females ($p = 0.002$) exhibited less distance error positioning objects in stereo compared to mono. Moreover, both males ($p = 0.002$) and females ($p = 0.0038$) made their decisions more quickly positioning objects in stereo. Both males ($p = 0.002$) and females ($p = 0.002$) had less distance error positioning objects casting a shadow than they did positioning objects with no cast shadow. Furthermore, both males ($p = 0.05$) and females ($p = 0.0008$) were *slower* positioning objects casting a shadow than they were positioning objects with no cast shadow.

4.3. Object resizing

In the object resizing task, there were significant differences in radius error magnitude ($p = 0.015$) as a function of gender. The overall mean male radius error

was 0.0674 units whereas the overall mean female radius error was 0.063 units. The difference in response time as a function of gender was not significant ($p = 0.41$). The overall mean male response time was 10.68 seconds whereas the overall mean female response time was 10.98 seconds.

To further investigate the gender-based impact of the depth cues on performance, a MANOVA model tested the effects of viewing mode and the presence of cast shadows on resizing accuracy and response times by gender. Table 3 presents the mean distance errors and response times by gender and depth cue for the object resizing experiment.

There was no significant difference among males ($p = 0.58$) or females ($p = 0.38$) in radius error while resizing objects viewed in stereo or mono. However, both males ($p = 0.002$) and females ($p = 0.0048$) were faster resizing objects viewed in stereo than in mono. There was also no difference in male ($p = 0.63$) or female ($p = 0.15$) radius error, nor in male response time ($p = 0.78$) resizing objects with or without a cast shadow. However, females were marginally *slower* ($p = 0.041$) resizing objects casting a shadow than they were resizing objects with no cast shadow.

5. Discussion

Table 4 indicates relative task performance advantages by gender in each experiment. The spatial abilities literature indicates a robust male performance advantage in *mental rotation* tasks, but no clear advantage for either gender in *spatial visualization* tasks. Accordingly, we anticipated a male advantage in the (mental rotation) object matching experiment, but no advantage for either gender in the (spatial visualization) object positioning and resizing experiments. Males did exhibit more accurate and faster performances than females in the object matching experiment (see Table 4). As this task was based on a mental rotation paradigm [41], and coupled with spatial literature meta-analyses indicating male advantages in mental rotation tasks and cognitive tests, it is consistent that the male subjects outperformed the female subjects in matching objects.

In contrast to the object matching experiment, in the object positioning and resizing (spatial visualization) experiments, the relative gender performances were mixed (see Table 4): males were more accurate positioning objects, whereas females were more accurate resizing objects. Moreover, there were no male-female differences in response times positioning nor resizing objects. Considering the positioning and resizing tasks individually, these findings are contrary to our speculation that there would be no relative male-female performance advantage for either the positioning or resizing tasks. However, considering the positioning and

resizing tasks as a collective category of spatial visualization tasks, these findings affirm our speculation: there was no dominant gender advantage across these two tasks. Males were more accurate positioning objects.

Females were more accurate resizing objects. Both genders were equally prompt performing each task.

Table 4. Summary of gender-based advantages in accuracy and response time performances for object matching, positioning, and resizing experiments

Experiment:	Accuracy/Gender:	RT/Gender:
Object Matching	Males more accurate	Males faster
Object Positioning	Males more accurate	No M/F difference
Object Resizing	Females more accurate	No M/F difference

To understand why males were more accurate positioning objects, whereas females were more accurate resizing objects, it is worthwhile to scrutinize the elements of each task. In this regard, object motion was a critical attribute for successfully positioning objects, but not for resizing objects. Accurately positioning the target object in a straight line segment required subjects to ‘fly’ the object around the visual space. This essential motion attribute may have contributed to a male performance advantage positioning objects and is consistent with previous findings that men typically outperform women in tasks manipulating objects in space [5] [11] [20] [21] [23] [25] [26]. In addition, the way-finding literature indicates that males have an advantage over females in estimating Euclidean distance and in finding Euclidean direction [4] [10] [32] [51]. In contrast, it has been demonstrated that females, compared to men, rely more on landmarks for way-finding [30] [32], and refer to landmarks when giving directions [32]. Consequently, the male subjects may have positioned objects more accurately due to males’ apparent advantage estimating Euclidean direction and distance.

In contrast, the females were more accurate than the males resizing the target object to match the apparent size of the referent object when both objects were fixed in position. Again, there was no male-female difference in resizing response time. The literature [7] [27] indicates that females outperform males in remembering the location of objects that are fixed in space. Resizing the target object required the ‘cognitive calibration’ of the relative apparent sizes of two objects that were displaced in their distances from the viewer, but otherwise fixed in position. There was no motion attribute integral to the resizing task. The female resizing accuracy advantage could be related to a female propensity to better recognize and remember the relative positions of landmark objects [9] [43]. Assuming a better sense of the relative fixed locations of the target and referent objects than males, females would be better able to calibrate the objects’ relative sizes since apparent

size is a function of correctly understanding the objects’ positions (relative to each other and relative from the viewer).

6. Conclusions and implications

In general, the results of these experiments indicate that:

- Males have a performance advantage over females in performing mental rotation tasks with abstract visual objects presented on computer-based media.
- Males make more effective use of certain motion-related cues than do females in performing computer-mediated visual tasks.
- Males and females generally perform equally well in ‘typical’ computer-mediated spatial visualization tasks.

Male advantages performing computer-mediated mental rotation tasks and using motion-related depth cues may imply similar advantages using related commercial and scientific visualizations. For example, it suggests a female handicap using existing 3D computer aided design (CAD) computer aided manufacturing (CAM) software applications. Design engineers use CAD-CAM applications to visually rotate an object under construction to ‘see’ what it looks like from various angles, or to determine whether it ‘fits’ into existing space constraints. Furthermore, females may be handicapped interpreting scientific data presented through the 3D rotation of ‘mesh’ and other abstract ‘wire frame’ designs. Fortunately, the majority of existing computer-mediated visual applications are not strictly tied to mental rotation tasks. Our findings suggest that ‘typical’ spatial visualization computer-mediated interfaces, in which users must observe, and perform various manipulations and transformations of visual abstractions representing data or other

information, should not entail a distinct performance advantage for either gender.

Rather than speculate and debate the existing visual applications with which males and/or females may enjoy performance advantages, it is more fruitful to suggest approaches to develop 'gender neutral' computer-mediated visual interfaces. One suggestion is to add meaningful landmarks and to decrease user reliance on 'spatial presence' and especially on mental rotation ability. For example, computer-based visual interface media that allow the stationary user to 'look right' or 'look left' (or up, down, backward, etc.) for familiar landmarks may prove to be an effective, gender-neutral orientation alternative to the use of typical motion cues, such as 'flying' around virtual spaces. The reliance on motion cues to extract information is especially problematic. (However, Czerwinski, Tan, and Robertson [6] and Tan, Robertson and Czerwinski [45] have demonstrated that male performance advantages are mitigated when males and females navigate virtual worlds using wider, 39 inch, displays.)

Another suggestion is to create user interface media that are *not strictly visual*. The introduction of meaningful textual information in an otherwise visual field is one approach. Visual interfaces that can be augmented with relevant text media at the user's discretion would likely prove to be effective for all users. Brief textual summaries of visual representations, even if redundant, attenuate the reliance on narrow perceptual channels and cognitive mechanisms to interpret and understand the presented information. Additionally, multi-modal cues that utilize non-visual sensory channels can help all users understand what is otherwise visually presented. For example, evoking simple sounds, such as a buzzer, or loud bell, to signify when real-time monitored data has crossed a danger threshold, can significantly augment meaningful information that is conveyed to the user in an otherwise strictly visual medium.

7. References

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